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(54) Title: TYROSINE KINASE (57) Abstract Tyrosine kinase mutant and wild-type genes useful in screening compositions which may affect DNA double-strand break repair activity.		

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1.

TYROSINE KINASE

BACKGROUND OF THE INVENTION

1. Field of The Invention

5 This invention relates generally to the molecular cloning of genes which can be used in toxicity assays and, specifically, to the isolation of a mammalian DNA recombination and repair gene which can be used in an assay to screen various compositions which affect DNA repair.

2. Related Art

10 Chromosomes experience single-stranded or double-stranded breaks as a result of energy-rich radiation, chemical agents, as well as spontaneous breaks occurring during replication among others. Although genes present in the chromosomes undergo continuous damage, repair, exchange, transposition, and splicing, certain enzymes protect or restore the specific base sequences of the chromosome.

15 The repair of DNA damage is a complex process that involves the coordination of a large number of gene products. This complexity is in part dependent upon both the form of DNA damage and cell cycle progression. For example, in response to ultraviolet (UV) irradiation, cells can employ photoreactivation or excision repair functions to correct genetic lesions. The
20 repair of strand breaks, such as those created by X-rays, can proceed through recombinational mechanisms. For many forms of DNA damage, the cell is induced to arrest in the G2 phase of the cell cycle. During this G2 arrest, lesions are repaired to ensure chromosomal integrity prior to mitotic segregation.

2.

5 Since the transfer of genetic information from generation to generation is dependent on the integrity of DNA, it is important to identify those gene products which affect or regulate genetic recombination and repair. Through the use of organisms with specific genetic mutations, the normal functional gene can be obtained, molecularly cloned, and the gene products studied.

10 Phenotypic complementation, as a way of identifying homologous normal functional genes, is widely used. For example, the human homologue of the yeast cell cycle control gene, *cdc 2*, was cloned by expressing a human cDNA library in *Schizosaccharomyces pombe* and selecting those clones which could complement a mutation in the yeast *cdc 2* gene (Lee, *et al.*, *Nature*, 327:31, 1987). A mammalian gene capable of reverting the heat shock sensitivity of the *RAS2^{val19}* gene of yeast, has also been cloned by using complementation (Colicelli, *et al.*, *Proc.Nat'l.Acad.Sci. USA*, 86:3599, 15 1989). A rat brain cDNA library was used to clone a mammalian cDNA that can complement the loss of growth control associated with the activated *RAS2* gene in yeast. The gene, DPD (dunce-like phosphodiesterase), encodes a high-affinity CAMP phosphodiesterase.

20 In eukaryotes such as *Saccharomyces cerevisiae*, genetic studies have defined repair-deficient mutants which have allowed the identification of more than 30 radiation-sensitive (*RAD*) mutants (Haynes, *et al.*, in *Molecular Biology of the Yeast Saccharomyces*, pp. 371, 1981; J. Game in *Yeast Genetics: Fundamental and Applied Aspects*, pp. 109, 1983). These mutants can be grouped into three classes depending upon their sensitivities. These classes broadly define excision-repair, error-prone repair, 25 and recombinational-repair functions. The molecular characterization of yeast *RAD* genes has increased the understanding of the enzymatic machinery involved in excision repair, as well as the arrest of cell division by DNA damage.

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5 The understanding of RAD genes and their expression products has become increasingly important as research continues to develop more effective therapeutic compositions. Often these new compositions appear quite effective against a particular disease condition, such as certain tumors, but prove to be too toxic for *in vivo* therapy in an animal having the disease. Indeed, these compositions can actually increase the likelihood of mutagenesis.

10 Most agents that are mutagenic or carcinogenic are in themselves unreactive, but are broken down to reactive intermediates *in vivo*. It is these reactive intermediates which interact with DNA to produce a mutation. This event is thought to be the initial step in chemical carcinogenesis. Mutations in a large number of genes affect the cellular response to agents that damage DNA. In all likelihood, many of these mutated genes encode enzymes that participate in DNA repair systems. Consequently, when the
15 repair system is compromised, the cells become extremely sensitive to toxic agents. Although the DNA may revert to normal when DNA repair mechanisms operate successfully, the failure of such mechanisms can result in a transformed tumor cell which continues to proliferate.

20 Although there are currently available tests to determine the toxicity or mutagenicity of chemical agents and compositions, there are limitations in both laboratory screening procedures and animal toxicity tests. These limitations include extrapolating laboratory data from animals to humans. There is often a large measure of uncertainty when attempting to correlate
25 the results obtained in laboratory animals with effects in human subjects. In most cases, doses of the test drug have been used in the animal which are too high to be safely administered to humans. In addition, some types of toxicity can be detected if the drug is administered in a particular species, yet may be missed if the experiment is not done in the correct animal

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species. Moreover, many currently available laboratory tests are incapable of detecting certain types of toxic manifestations which occur in man.

5 Drugs are also routinely tested for their mutagenic potential using microorganisms in the screening assay. The popular test developed by Ames and colleagues (Ames, *et al.*, *Mutat. Res.*:31, 347, 1975) uses *Salmonella typhimurium* containing a mutant gene for histidine synthesis. This bacterial strain cannot grow in a histidine deficient medium unless a reverse mutation is induced by exposure to a particular agent. The Ames test is rapid and sensitive, however, its usefulness in predicting carcinogenic
10 or mutagenic potential of chemical substances in human is unclear.

15 In summary, limitations and uncertainties of existing laboratory tests fail to provide an accurate method of examining the effects of a composition on DNA integrity. In view of this, a considerable need exists for screening methodologies which are inexpensive, rapid, and contain the relevant gene from the animal which is to be treated with the composition. Such methods provide a direct assay to determine if a composition interferes with the DNA repair system of a cell.

SUMMARY OF THE INVENTION

5 The present invention arose from the discovery of a novel protein which is involved in repair of DNA strand breaks. Although this protein has kinase activity, it is the only kinase known to promote repair of DNA strand breaks occurring at a specific nucleotide sequence and allow normal mitotic recombination. The identification of the normal, or "wild-type", protein kinase was made possible by the isolation of a yeast mutant (*hrr25*) defective in repairing DNA strand breaks, but still capable of promoting normal mitotic recombination. The wild-type gene (*HRR25*) was isolated by screening a
10 DNA library for nucleotide sequences which could restore the ability to repair DNA breaks.

A major advantage of the present invention is that it now enables identification of functionally analogous wild-type proteins from other species, especially humans. The identification of such foreign protein provides the
15 further advantage of allowing their use in a screening method designed to examine the effect of various compositions on the DNA break repair promoting activity of the foreign protein.

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BRIEF DESCRIPTION OF THE DRAWINGS

5 FIGURE 1(A) shows the nucleotide and amino acid sequence of the *HRR25* gene. The locations of the prolines and glutamines at the C-terminus are indicated by asterisks and the limits of homology to the protein kinase catalytic domain are shown by arrows. (B) shows the protein kinase homology represented by a shaded region while the P/Q rich region is indicated by cross hatching.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

5 The present invention relates to a DNA recombination and repair gene which can be used in an assay system to examine the effects of various compositions on DNA integrity. The invention also provides a DNA sequence encoding a polypeptide which promotes normal mitotic recombination, but is defective in tyrosine kinase activity and essentially
10 useful for identifying other DNA sequences which encode proteins with functional tyrosine kinase activity. These functional sequences, which can be characterized by their ability to restore DNA strand breaks, permit the screening of compositions to determine whether a particular composition has an effect on the restoration of such repair activity. In addition, the present invention relates to the polypeptide encoded by the defective DNA
15 sequence, as well as the polypeptide encoded by the functional wild-type DNA.

In order to identify a DNA sequence encoding a polypeptide with tyrosine kinase activity, a method is provided whereby a DNA library is screened for nucleotide sequences capable of restoring DNA strand break repair in a
20 mutant lacking such activity. A method is further provided for identifying a composition which affects the activity of a mammalian polypeptide having tyrosine kinase activity, wherein the polypeptide is capable of restoring DNA double-strand break repair activity in a mutant lacking such activity.

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In general, the defective protein kinase can be characterized by its ability to promote normal mitotic recombination, while being essentially unable to repair DNA double-strand break including that which occurs at the cleavage site:

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CAACAG[↓]
GTTGTC[↑]

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The DNA double-strand breaks which the defective protein kinase is essentially unable to repair can be induced by various means, including endonucleases, x-rays, or radiomimetic agents including alkylating agents. Preferred endonucleases are those which recognize the same nucleotide cleavage site as endonuclease *HO*. Radiomimetic alkylating agents having methylmethane sulfonate activity are preferred. Those of skill in the art will be able to identify other agents which induce the appropriate DNA strand breaks without undue experimentation.

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The present invention specifically discloses mutants sensitive to continuous expression of the DNA double-strand endonuclease *HO*, which codes for a 65 kDa site-specific endonuclease that initiates mating type interconversion (Kostriken, *et al.*, *Cold Spring Harbor Symp. Quant. Biol.*, 49:89, 1984). These mutants are important to understanding the functions involved in recognizing and repairing damaged chromosomes. This invention also discloses a yeast wild-type DNA recombination and repair gene called *HRR25* (*HO* and/or radiation repair). Homozygous mutant strains, *hrr25-1*, are sensitive to methylmethane sulfonate and X-rays, but not UV irradiation. The wild-type gene encodes a novel protein kinase, homologous to other serine/threonine kinases, which appears critical in activation of DNA repair functions by phosphorylation.

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5 The *HRR25* kinase is important for normal cell growth, nuclear segregation, DNA repair and meiosis, and deletion of *HRR25* results in cell cycle defects. These phenotypes, coupled with the sequence similarities between the *HRR25* kinase and the *Raf/c-mos* protein kinase subgroup suggest that *HRR25* might play a similar role in *S. cerevisiae* growth and development. The defects in DNA strand break repair and the aberrant growth properties revealed by mutations in *HRR25* kinase, expands the role that protein kinases may play and places *HRR25* in a functional category of proteins associated with DNA metabolism.

10 The development of specific DNA sequences encoding protein kinase polypeptides of the invention can be accomplished using a variety of techniques. For example, methods which can be employed include (1) isolation of a double-stranded DNA sequence from the genomic DNA of the eukaryote; (2) chemical synthesis of a DNA sequence to provide the
15 necessary codons for the polypeptide of interest; and (3) *in vitro* synthesis of a double stranded DNA sequence by reverse transcription of mRNA isolated from a eukaryotic donor cell. In the latter case, a double stranded DNA complement of mRNA is eventually formed which is generally referred to as cDNA.

20 The novel DNA sequences of the invention include all sequences useful in providing for expression in prokaryotic or eukaryotic host cells of polypeptides which exhibit the functional characteristics of the novel protein kinase of the invention. These DNA sequences comprise: (a) the DNA sequences as set forth in Figure 1 or their complementary strands; (b) DNA
25 sequences which encode an amino acid sequence with at least about 35% homology in the protein kinase domain with the amino acid sequences encoded by the DNA sequences defined in (a) or fragments thereof; and (c) DNA sequences defined in (a) and (b) above. Specifically embraced in (b) are genomic DNA sequences which encode allelic variant forms. Part (c)

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specifically embraces the manufacture of DNA sequences which encode fragments of the protein kinase and analogs of the protein kinase wherein the DNA sequences thereof may incorporate codons which facilitate translation of mRNA. Also included in part (c) are DNA sequences which are degenerate as a result of the genetic code.

Since the DNA sequence of the invention encodes essentially the entire protein kinase molecule, it is now a routine matter to prepare, subclone, and express smaller polypeptide fragments of DNA from this or a corresponding DNA sequence. The term "polypeptide" denotes any sequence of amino acids having the characteristic activity of the mutant or wild-type protein kinase of the invention, wherein the sequence of amino acids is encoded by all or part of the DNA sequences of the invention.

The polypeptide resulting from expression of the DNA sequence of the invention can be further characterized as being free from association with other eukaryotic polypeptides or other contaminants which might otherwise be associated with the protein kinase in its natural cellular environment.

Isolation and purification of microbially expressed polypeptides provided by the invention may be by conventional means including, preparative chromatographic separations and immunological separations involving monoclonal and/or polyclonal antibody preparation.

In general, expression vectors useful in the present invention contain a promotor sequence which facilitates the efficient transcription of the inserted eukaryotic genetic sequence. The expression vector typically contains an origin of replication, a promoter, and a terminator, as well as specific genes which are capable of providing phenotypic selection of the transformed cells. The transformed hosts can be grown in fermentors and cultured according to techniques known in the art to achieve optimal cell growth. The

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polypeptides of the invention can then be isolated from the growth medium, cellular lysates, or cellular membrane fractions.

5 The DNA sequences of the present invention can be expressed *in vivo* in either prokaryotes or eukaryotes. Methods of expressing DNA sequences containing eukaryotic coding sequences in prokaryotes are well known in the art. Biologically functional viral and plasmid DNA vectors used to incorporate DNA sequences of the invention, for expression and replication in the host cell are well known in the art. For example, DNA can be inserted in yeast using appropriate vectors and introducing the product into the host cells. Various shuttle vectors for the expression of foreign genes in yeast 10 have been reported (Heinemann, *et al.*, *Nature*, 340:205, 1989; Rose, *et al.*, *Gene*, 60:237, 1987). Those of skill in the art will know of appropriate techniques for obtaining gene expression in both prokaryotes and eukaryotes, or can readily ascertain such techniques, without undue experimentation. 15

Hosts include microbial, yeast and mammalian host organisms. Thus, the term "host" is meant to include not only prokaryotes, but also such eukaryotes such as yeast, filamentous fungi, as well as plant and animal cells which can replicate and express an intron-free DNA sequence of the invention. The term also includes any progeny of the subject cell. It is 20 understood that not all progeny are identical to the parental cell since there may be mutations that occur at replication. However, such progeny are included when the terms above are used.

Transformation with recombinant DNA may be carried out by conventional techniques well known to those skilled in the art. Where the host is 25 prokaryotic, such as *E. coli*, competent cells which are capable of DNA uptake can be prepared from cells harvested after exponential growth phase and subsequently treated by the CaCl_2 method using procedures well

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known in the art. Alternatively, $MgCl_2$ or $RbCl$ could be used in the reaction. Transformation can also be performed after forming a protoplast of the host cell.

5 Where the host is a eukaryote, various methods of DNA transfer can be used. These include transfection of DNA by calcium phosphate-precipitates, conventional mechanical procedures such as microinjection, insertion of a plasmid encased in liposomes, spheroplast electroporation, salt mediated transformation of unicellular organisms or the use of virus vectors.

10 Analysis of eukaryotic DNA has been greatly simplified since eukaryotic DNA can be cloned in prokaryotes using vectors well known in the art. Such cloned sequences can be obtained easily in large amounts and can be altered *in vivo* by bacterial genetic techniques and *in vitro* by specific enzyme modifications. To determine the effects of these experimentally induced changes on the function and expression of eukaryotic genes, the
15 rearranged sequences must be taken out of the bacteria in which they were cloned and reintroduced into a eukaryotic organism. Since there are still many functions in eukaryotic cells which are absent in prokaryotes, (e.g., localization of ATP-generating systems to mitochondria, association of DNA with histones, mitosis and meiosis, and differentiation of cells), the genetic
20 control of such functions must be assessed in a eukaryotic environment. Cloning genes from other eukaryotes in yeast has been useful for analyzing the cloned eukaryotic genes as well as other yeast genes. A number of different yeast vectors have been constructed for this purpose. All vectors replicate in *E. coli*, which is important for amplification of the vector DNA.
25 All vectors contain markers, e.g., LEU 2, HIS 3, URA 3, that can be selected easily in yeast. In addition, these vectors also carry antibiotic resistance markers for use in *E. coli*.

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5 Many strategies for cloning human homologues of known yeast genes are known in the art. These include, but are not limited to: 1) low stringency hybridization to detect shared nucleotide sequences; 2) antibody screening of expression libraries to detect shared structural features; and 3) complementation of mutants to detect genes with similar functions.

10 For purposes of the present invention, protein kinases which are homologous can be identified by structural as well as functional similarity. Structural similarity can be determined, for example, by assessing amino acid homology or by screening with antibody, especially a monoclonal antibody, which recognizes a unique epitope present on the protein kinases of the invention. When amino acid homology is used as criteria to establish structural similarity, those amino acid sequences which have homology of at least about 35% in the protein kinase domain are considered to be essentially the same as the amino acid sequences of the invention.

15 When homologous amino acid sequences are evaluated based on functional characteristics, then a homologous amino acid sequence is considered equivalent to the amino acid sequence of the invention when the homologous sequence is essentially unable to repair (in the case of the repair defective mutant gene) or able to repair (in the case of the natural gene), DNA double-strand breaks, including that which occurs at a nucleotide cleavage site

25 CAACAG
GTTGTC
↑

and when the homologous amino acid sequence allows normal mitotic recombination.

This invention preferably uses the functional screening method whereby genes are cloned from plasmid libraries by complementation of a recessive

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5 marker. A recipient strain such as *Saccharomyces cerevisiae* is constructed that carries a recessive mutation in the gene of interest. This strain is then transformed with a plasmid, for example, pYES2 (Invitrogen, San Diego, CA) containing the wild-type genomic DNA or cDNA. The clone carrying the gene of interest can then be selected by replica plating to a medium that distinguishes mutant from wild-type phenotypes for the gene of interest. The plasmid can then be extracted from the clone and the DNA studied. Several yeast vectors allow the application of complementation systems to go beyond isolation of yeast genes. Genes from a wide variety of species can be isolated using these vectors. In such systems, DNA sequences from 10 any source are cloned into a vector and can be screened directly in yeast for activities that will complement specific yeast mutations.

15 In a preferred embodiment, the present invention uses a mutation in yeast, the *hrr25* mutation, which was identified by sensitivity to DNA double-strand breaks induced by the HO endonuclease. The genomic DNA which complements this mutation was isolated by transforming the *hrr25* strain with a DNA library and subsequently screening for methylmethane sulfonate (MMS) resistance. Alternately, functional genes from a variety of mammalian species can now be cloned using the system described.

20 Yeast genes can be cloned by a variety of techniques, including use of purified RNA as hybridization probes, differential hybridization of regulated RNA transcripts, antibody screening, transposon mutagenesis, cross suppression of mutant phenotypes, cross hybridization with heterologous cDNA or oligonucleotide probes, as well as by complementation in *E. coli*.

25 Minor modifications of the primary amino acid sequence may result in proteins which have substantially equivalent or enhanced activity as compared to the sequence set forth in Figure 1. The modifications may be deliberate, as by site-directed mutagenesis, or may be spontaneous by

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HRR25 producing organisms. All of these modifications are included in the invention as long as *HRR25* activity is retained. Substitution of an aspartic acid residue for a glycine acid residue at position 151 in the sequence shown in FIGURE 1 identifies the mutant *hrr25*.

5 Antibodies provided by the present invention are immunoreactive with the mutant polypeptides and/or the naturally occurring protein kinase. Antibody which consist essentially of numerous monoclonal antibodies with different epitopic specificities, as well as distinct monoclonal antibody preparations are provided. Monoclonal antibody is made from antigen containing
10 fragments of the polypeptide by methods well known in the art (Kohler, G. *et al.*, *Nature* 256:495, 1975; *Current Protocols in Molecular Biology*, Ausubel, F. *et al.*, ed., 1989).

15 The invention also discloses a method for identifying a composition which affects the activity of a polypeptide having tyrosine kinase activity. The polypeptide is capable of restoring DNA double-strand break repair activity in host cells containing the *hrr25* gene. The composition and the polypeptide are incubated in combination with host cells for a period of time and under conditions sufficient to allow the components to interact, then
20 subsequently monitoring the change in tyrosine kinase activity, for example, by decreased repair of DNA double-strand breaks. The DNA strand breaks are induced, for example, by a radiomimetic agent, such as methylmethane sulfonate, x-rays, or by endonuclease like *HO*. Other means of inducing double-strand breaks that are well known in the art may be employed as well.

25 The following examples are intended to illustrate but not limit the invention. While they are typical of those that might be used, other procedures known to those skilled in the art may alternatively be used.

EXAMPLE 1

ISOLATION OF *hrr25*

5 *S. cerevisiae* strain K264-5B (*MAT α ho ura3 can1^R tyr1 his7 lys2 ade5 met13 trp5 leu1 ade5*) was employed for the mutant isolation. The yeast were transformed according to standard procedures with a *URA3*-based integrating plasmid that contained a *GAL1,10*-regulated *HO* endonuclease and a transformant was mutagenized to approximately 50% survival with ethyl methanesulfonate (EMS), as described (*Current Protocols in Molecular Biology, supra*). The culture was spread onto glycerol-containing rich medium (YPG, to avoid petites), colonies were allowed to form at 30°C, and plates were replicated to glucose (*HO* repressing) and galactose (*HO* inducing) media. Mutants were identified by their inability to grow on galactose. Approximately 200 mutants were chosen for initial characterization and 62 maintained the *gal*- phenotype through repeated single colony purification. Among these, many were not complemented by various *gal* mutants. The remainder (25 mutants) were surveyed for overlapping DNA repair defects by determining sensitivity to ultraviolet (UV) irradiation and to methyl methane sulfonate (MMS). This screening method identified five alleles of known *rad* mutations and one new mutation. This new mutation *hrr25-1* (*HO* and/or radiation repair), presented severe defects and was studied further.

25 A recessive DNA repair defect is conferred by *hrr25-1* that includes sensitivity to MMS. *Hrr25-1* strains also show sensitivity at 5-20 Krad X-irradiation similar to that observed with mutations in the radiation repair genes *RAD50* and *RAD52* (Cole, et al., *Mol.Cell.Biol.*, 9:3101, 1989). The *hrr25-1* strains are no more sensitive to UV irradiation than wild type and are not temperature sensitive for growth at 37°C. Unlike hypo- and hyper-rec *rad* mutants which have several of the *hrr25-1* phenotypes, *hrr25-1* strains

undergo normal mitotic recombination (Cole, *et al.*, *Mol.Cell.Biol.*, 9:3101, 1989). Spontaneous gene conversion and crossing-over were the same for homozygous *hrr25-1* and wild type strains. However, *HRR25* is required for the correct completion of meiosis. The *hrr25-1* homozygotes showed less than 1% spores (tetranucleate cells) under conditions that produced 75-80% spores in an isogenic wild type strain. The *hrr25-1* mutation could be complemented by a number of radiation sensitive mutations (*rad6*, 50, 52, 54, and 57) that present some of the *hrr25* phenotypes, suggesting that *hrr25-1* is a newly uncovered *rad*-like mutation and not one of these previously described genes. These results also indicate that *HRR25* plays a role in DNA repair and meiosis, but is not specifically required for the repair of spontaneous mitotic lesions by recombination.

EXAMPLE 2

ISOLATION OF *HRR25*

The *HRR25* gene was obtained by complementing for MMS sensitivity using a yeast genomic library constructed in the plasmid YCp50 (Rose, *et al.*, *Gene*, 60:237, 1987). An *hrr25-1* strain, MHML 3-36d (*ura3 hrr25*), was transformed by standard methods (Nickoloff, *et al.*, *J.Mol.Biol.*, 207:527, 1989) to uracil prototrophy, transformants were amplified on media without uracil and replicated to media containing 0.01% MMS. Among 1200 transformants, a single MMS resistant isolate was identified. Complementation for MMS sensitivity was found to segregate with the plasmid as determined by methods known in the art.

A 12 kb genomic fragment was identified and complementing activity was localized to a 3.1 kb *Bam*HI-*Sa*II fragment by transposon mutagenesis and subcloning. This region complemented DNA repair defects as well as meiotic deficiencies. Gene targeting experiments linked this cloned region

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to *hrr25-1*. Transposon insertion mutations within the *Bam*HI-*Sa*II fragment replaced into the cognate *HRR25* genomic locus did not complement *hrr25-1* for MMS sensitivity, whereas adjacent chromosomal insertions outside the complementing region segregated in repulsion when crossed against *hrr25-1*.

Mini-Tn10LUK transposons (Huisman, *et al.*, *Genetics*, 116:191, 1987) were used to delineate the approximate location of *HRR25* on the 12 kb *Bam*HI-*Sa*II fragment. Insertions located to the left hand 9 kb (of the 12 kb genomic fragment) did not inactivate complementation of *hrr25-1* MMS resistance compared with the un-mutagenized plasmid. Two insertions, located near an *Eco*RV site in the right hand 2 kb inactivated complementation. *HRR25* complementation activity was localized to a 3.4 kb *Sa*II fragment. Approximately 300 bp of this fragment (right hand side of the 12 kb) were part of the pBR322 tetracycline resistance gene (between the *Bam*HI site of pBR322-based YCp50). The *HRR25* open reading frame spans an internal region across an *Eco*RV site and two *Bg*II sites within the right terminal 3 kb.

The DNA sequence of the 3.1 kb fragment revealed a centrally located open reading frame of 1482 nucleotide. A transposon insertion mutation in this open reading frame inactivated *HRR25* complementation whereas insertions elsewhere in the 12 kb clone did not affect *HRR25* complementation. Transposon-mediated disruption of *HRR25* also revealed several phenotypes not seen with *hrr25-1*. As expected, a Tn10-based LUK transposon insertion (Huisman, *et al.*, *Genetics*, 116:191, 1987) into the middle of plasmid-borne *HRR25* coding region inactivated complementation for MMS sensitivity. Transplacement of this insertion into the genomic *HRR25* gene revealed a severe growth defect in addition to MMS sensitivity and meiotic inviability. This severe growth defect was not observed with *hrr25-1* strains. Wild type *HRR25* strains doubled in rich media at 30°C every 80-90 minutes whereas

isogenic *hrr25::LUK* strains and *hrr25Δ* doubled every 9-12 hours. *hrr25-1* had a doubling time of 2-4 hours.

To determine whether the mutant phenotypes revealed by the *hrr::LUK* disruption allele represent a null phenotype, the entire *HRR25* coding sequence was deleted. Briefly, deletion of the *HRR25* coding sequence employed a *hisG::URA3::hisG* cassette (Alani, *et al.*, *Genetics*, 116:541, 1988). The 3.1 kb *HRR25* *Sal*I fragment was cloned into pBluescript (Stratagene, La Jolla, CA). This plasmid was digested with *Bgl*II and the two *Bgl*II fragments that span the entire *HRR25* gene and its flanking sequences were deleted. Into this deletion was introduced the 3.8kb *Bam*HI-*Bgl*II *hisG::URA3::hisG* fragment from pNKY51 to create the *hrr25Δ* allele. *Sal*I digestion yielded a linearized fragment that deleted the entire *HRR25* locus. Yeast carrying the deletion-disruption allele (*hrr25Δ*) showed phenotypes identical to those with the *hrr25::LUK* allele for all properties examined, including MMS sensitivity, slow growth, and the sporulation defect, indicating that wild-type *HRR25* protein is associated with these processes and that the *hrr25::LUK* allele does not indirectly interfere with DNA repair, growth or sporulation. In direct parallel comparisons, the *hrr25::LUK* and *hrr25Δ* alleles behaved identically.

Yeast strain MFH14 (*MATa/MATα ura3/ura3*) was transformed with *Bgl*II-linearized YCp50-*HRR25::LUK* to uracil prototrophy, heterozygous disruption of *HRR25* was verified by Southern blot analysis, the diploid was sporulated by starvation for nitrogen and fermentable carbon source, tetrads dissected and cells allowed to germinate at 30°C for 7 days. After a normal germination period of 2 days, the severe growth defect of *hrr25::LUK* suggested that the deletion of *HRR25* was lethal. However, microscopic examination of segregants revealed that *hrr25::LUK* germinating cells grew slowly and in every case examined (20/20 tetrads), slow growth, MMS sensitivity, and uracil prototrophy co-segregated. A color variation was seen

seen with diploid MFH14 segregants, due to mutations in adenine biosynthesis. MFH14 is *ade5/ADE5 ade2/ade2*. An *ade5/ade2* strain was white, while an *ADE5/ade2* strain was red.

EXAMPLE 3

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SEQUENCE AND STRUCTURE OF THE *HRR25* GENE

DNA sequencing of both strands of the *HRR25* gene was done by unidirectional deletions employing Sequenase (USB, Cleveland, OH) and Exo-Meth (Stratagene, La Jolla, CA) procedures as described by the manufacturers. Figure 1A, shows the location of the prolines and glutamines at the C-terminus as indicated by asterisks, and the limits of homology to protein kinase catalytic domains. Figure 1B shows a schematic representation of the structure of *HRR25*. The protein kinase homology is represented by a shaded region while the P/Q rich region is indicated by cross-hatchings. The mutant, *hrr25*, can be distinguished from *HRR25* by one amino acid substitution. At position 151, an aspartic acid is substituted for glycine.

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The predicted translation product of *HRR25* revealed an unexpected feature for a *rad*-like DNA repair function. *HRR25* contains the hallmark signatures of sequence homology with the catalytic domain of serine/threonine protein kinase superfamily members (Hanks, *et al.*, *Science*, 241:42, 1988). For comparison, the *HRR25* translation product was aligned with the catalytic domains for two subgroups of yeast protein kinases, the *CDC28/cdc2* group and the *KSS1/FUS3* group. Located between amino acids 15 and 30 is a region that contains the conserved GXGXXG region. Just C-terminal to this region is a conserved lysine and glutamic acid present in most known kinases. These regions are thought to function in the nucleotide binding

21.

5 and phosphotransfer steps of the kinase reaction (Hanks, *et al.*, *Science*, 241:42,1988). Between amino acid residues 120 to 150 are regions containing the HRD and DFG motifs, also found in most protein kinase family members. In addition, sequence examination of all known serine/threonine kinases indicates that *HRR25* shares some additional similarities with the *Raf/PKS/mos* subgroup (Hanks, *et al.*, *Science*, 241:42, 1988). The strongest homologies can be found in areas around the GXGXXG, DFG, and DXSXG conserved regions in protein kinase catalytic domains.

10 The functional relevance of the observed sequence similarity between *HRR25* and protein kinases was studied by altering specific residues within the *HRR25* kinase domain and examining the phenotypic consequences of these changes. A lysine at position 38 (Lys³⁸) was mutated to an arginine residue by site directed mutagenesis, by methods known in the art. The mutagenic
15 oligonucleotide was:

5'-CCTGATCGATTCCAGCCTGATCGCTACTTCTTCACCACT-3'.

Lys³⁸ in *HRR25* corresponds to the lysine found in all known protein kinases, and this subdomain is involved in ATP binding. Mutations at the conserved lysine in protein kinases such as *v-src*, *v-mos*, and *DBF2* inactivate these
20 proteins. The mutant *hrr25*-Lys³⁸ allele was incapable of complementing *hrr25-1*, *hrr25::LUK*, and *hrr25Δ* alleles for all properties examined, an indication that the *HRR25* kinase domain is required for *in vivo* function of *HRR25*.

25 The predicted *HRR25* translation product has a number of notable features outside the region of homology to protein kinase catalytic domains. For example, the last 100 amino acids is proline and glutamine rich, containing 50 of these residues. Other proteins with regions rich in these two amino

acids include the transcription factors *Sp1*, *jun*, and *HAP2*, steroid hormone receptors, the *S. pombe ran1* kinase, and *mak*-male germ cell-associated kinase (Courey, *et al.*, *Cell*, 55:887, 1988; Bohmann, *et al.*, *Science*, 238:1386, 1987; Roussou, *et al.*, *Mol.Cell.Biol.*, 8:2132, 1988; Arriza, *et al.*, *Science*, 237:268, 1987; Matsushime, *et al.*, *Mol.Cell.Biol.*, 10:2261, 1990). In the case of *Sp1* and *jun*, the proline-glutamine regions are involved in transactivation, whereas the P/Q region in the human mineralocorticoid receptor is thought to serve as an intramolecular bridge. This proline-glutamine region in *HRR25* might function as a structural feature for substrate interaction, or for subcellular localization. Also, the glutamine richness of this region is similar to the *opa* or M-repeat seen in the *Drosophila* and *Xenopus Notch/Xotch* proteins (Wharton, *et al.*, *Cell*, 40:55, 1985; Coffman, *et al.*, *Science*, 249:1438, 1990). The function of the *opa* repeat is not certain, but it is found in several *Drosophila* genes. Lastly, the sequence TKKQKY at the C-terminal end of the region homologous to protein kinases is similar to the nuclear localizing signal of SV40 large T antigen and yeast histone H2B (Silver, *et al.*, *J.Cell.Biol.*, 109:983, 1989; Moreland, *et al.*, *Mol.Cell.Biol.*, 7:4048, 1987).

EXAMPLE 4

MICROSCOPIC ANALYSIS OF GERMINATING AND PROLIFERATING *hrr25* CELLS

Photomicrographs of *HRR25* and *hrr25::LUK* colonies were taken after germination on rich medium. An MFH14 *hrr25::LUK* heterozygous transformant was dissected onto a thin film of YPD rich medium on a sterilized microscope slide and segregants were allowed to germinate under a coverslip by incubating the slide in a moist 30°C chamber. Photographs of colonies were taken after 2 days of growth. Phase contrast and DAPI staining of proliferating *HRR25Δ* and *hrr25::LUK* cells were compared. Cells

23.

were inoculated into YPD rich medium and grown at 30°C to a mid-log density of $1-3 \times 10^7$ cells/ml, briefly sonicated to disrupt clumps, fixed with formaldehyde, and stained with DAPI (Williamson, *et al.*, *Meth.Cell.Biol.*, 12:335, 1975). Many cells with *hrr25::LUK* lacked DAPI stainable nuclei.

5 Microscopic examination of germinating and actively growing mid-log phase *hrr25::LUK* cells revealed aberrant cellular morphologies. Transposon disruption of *HRR25* resulted in large cells, and 25-40% of cells were filamentous or extended. DAPI nuclear staining (Williamson, *et al.*, *Meth.Cell.Biol.*, 12:335, 1975) of mid-log populations showed that orderly
10 cell cycle progression in *hrr25* mutants was lost. There were a large number of cells lacking DAPI-stainable nuclei which, by single cell manipulations proved to be inviable. Consistent with this nuclear segregation defect, the plating efficiency of *hrr25::LUK* haploids was also reduced to 75-80% of wild type. However, this reduction in plating efficiency is insufficient to account
15 for the severe growth rate reduction. Plating efficiency was measured from mid-log phase cells by comparing the efficiency of colony formation on rich medium relative to the total number of cells determined by hemocytometer count. Cell populations were analyzed for DNA content distribution by flow cytometric analysis following staining with propidium iodide as described
20 (Hutter, *et al. J.Gen.Microbiol.*, 113:369, 1979). Cell sorting analysis showed that a large number of the cells in a haploid *hrr25::LUK* population were delayed in the cell cycle and exhibited G2 DNA content, but the population was not arrested uniformly in the cell cycle.

EXAMPLE 5**SEQUENCE COMPARISON OF HRR25 WITH
CDC28, KSS1, AND RAF1**

5 The predicted translation product of *HRR25* was compared with the catalytic domains of several members of the serine/threonine protein kinase superfamily. Initial sequence comparisons employed the UWGCG programs (Devereux, *et al.*, *Nuc.Acids.Res.*, 12:387, 1984), whereas subgroup comparisons used the methods of Hanks, *et al.*, *supra*. *HRR25* contains all eleven subdomains described by Hanks, *et al.*, *supra*. Structurally similar
10 groupings were compared in the sequence comparisons. These included nonpolar chain R groups, aromatic or ring-containing R groups, small R groups with near neutral polarity, acidic R groups, uncharged polar R groups, and basic polar R groups.

15 *CDC28* and *KSS1* represent members of two subgroups of serine/threonine protein kinases in yeast. *CDC28* is involved in cell cycle regulation while *KSS1* acts in the regulation of the yeast mating pathway. *HRR25* shows 21% identity and 41% similarity to *CDC28* and 19% identity and 43% similarity to *KSS1*. *HRR25* shows highest similarity to members of the *Raf1/PKS/Mos* family of protein kinases. Through the catalytic domain,
20 *HRR25* shows 30% identity and 49% similarity to *Raf1*.

25.

SUMMARY OF SEQUENCES

Sequence I.D. No. 1 is the nucleic acid sequence (and the deduced amino acid sequence) of a genomic fragment encoding a yeast-derived tyrosine kinase of the present invention.

- 5 Sequence I.D. No. 2 is the deduced amino acid sequence of a yeast-derived tyrosine of the present invention.

26.

SEQUENCE LISTING

(1) GENERAL INFORMATION:

(i) APPLICANT: Hoekstra, Merl F.

(ii) TITLE OF INVENTION: TYROSINE KINASE

5 (iii) NUMBER OF SEQUENCES: 2

(iv) CORRESPONDENCE ADDRESS:

10 (A) ADDRESSEE: Spensley Horn Jubas & Lubitz
(B) STREET: 4225 Executive Square, Suite 1400
(C) CITY: La Jolla
(D) STATE: CA
(E) COUNTRY: USA
(F) ZIP: 92037

(v) COMPUTER READABLE FORM:

15 (A) MEDIUM TYPE: Floppy disk
(B) COMPUTER: IBM PC compatible
(C) OPERATING SYSTEM: PC-DOS/MS-DOS
(D) SOFTWARE: PatentIn Release #1.0, Version #1.25

(vi) CURRENT APPLICATION DATA:

20 (A) APPLICATION NUMBER: US
(B) FILING DATE: 03-JUL-1991
(C) CLASSIFICATION:

27.

(viii) ATTORNEY/AGENT INFORMATION:

- (A) NAME: Wetherell Ph.D., John R.
- (B) REGISTRATION NUMBER: 13,678
- (C) REFERENCE/DOCKET NUMBER: PD-1318

5

(ix) TELECOMMUNICATION INFORMATION:

- (A) TELEPHONE: (619) 455-5100
- (B) TELEFAX: (619) 455-5110

(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:

10

- (A) LENGTH: 3098 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

15

(vii) IMMEDIATE SOURCE:

- (B) CLONE: Tyrosine Kinase

(ix) FEATURE:

- (A) NAME/KEY: CDS
- (B) LOCATION: 879..2364

28.

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

	GTCTGACTCGC CAATCACCAA GTTCTTATCC CACATCCGAC CAGTGTCTGA GTCATGGTTT	60
	ACCACCACCA TACCATCGCT GGTCAATTTGT AAATCCGTTT CTATTACATC AGCACCTGCT	120
	GCATAAGCCT TCTCAAATGC TAGTAGCGTA TTTTCAGGAT ATCTTGCTTT AAAAGCTCTG	180
5	TGGCCACAA TTCAACCAT CCTCGTGTCC TTGTTGTTAT CTTACACTTC TTATTTATCA	240
	ATAACACTAG TAACATCAAC AACACCAATT TTATATCTCC CTTAATTGTA TACTAAAAGA	300
	TCTAAACCAA TTCGGTATTG TCCTCGATAC GGCATGCGTA TAAAGAGATA TAATTAAAAG	360
	AGGTTATAGT CAGGTGATGC AGATTACCCG CAACAGTACC ACAAATGGA TACCATCTAA	420
	TTGCTATAAA AGGCTCCTAT ATACGAATAA CTACCACTGG ATCGACGATT ATTCGTGGC	480
10	AATCATATAC CACTGTGAAG AGTTACTGCA ACTCTCGCTT TGTTTCAACG CTCCTTCCCG	540
	TCTGTGTATT TACTACTAAT AGGCAGCCCA CGTTTGAATT TCTTTTTTTC TGGAGAATTT	600
	TTGGTGCAAC GAGGAAAAGG AGACGAAGAA AAAAAGTTGA AACACGACCA CATATATGGA	660
	ACGTGGTTGA AATACAAAGA GAAGAAAGGT TCGACACTCG AGGAAAGCAT TTGGTGGTGA	720
	AAACACATCT TAGTAGCATC TTAAACCTC TGTTGGGTAC TTAGAAAAAT ATTCCAGAC	780
15	TTCAAGGATA AAAAAAGTCG AAAAGTTACG ACATATTGGA CCAAAAAAAA AAACCAAAAA	840

29.

	GAAAAGATAT ATTTATAGAA AGGATACATT AAAAAGAG ATG GAC TTA AGA GTA	893
	Met Asp Leu Arg Val	
	1 5	
5	GGA AGG AAA TTT CGT ATT GGC AGG AAG ATT GGG AGT GGT TCC TTT GGT Gly Arg Lys Phe Arg Ile Gly Arg Lys Ile Gly Ser Gly Ser Phe Gly	941
	10 15 20	
	GAC ATT TAC CAC GGC ACG AAC TTA ATT AGT GGT GAA GAA GTA GCC ATC	989
	Asp Ile Tyr His Gly Thr Asn Leu Ile Ser Gly Glu Glu Val Ala Ile	
	25 30 35	
10	AAG CTG GAA TCG ATC AGG TCC AGA CAT CCT CAA TTG GAC TAT GAG TCC	1037
	Lys Leu Glu Ser Ile Arg Ser Arg His Pro Gln Leu Asp Tyr Glu Ser	
	40 45 50	
	CGC GTC TAC AGA TAC TTA AGC GGT GGT GTG GGA ATC CCG TTC ATC AGA	1085
15	Arg Val Tyr Arg Tyr Leu Ser Gly Gly Val Gly Ile Pro Phe Ile Arg	
	55 60 65	
	TGG TTT GGC AGA GAG GGT GAA TAT AAT GCT ATG GTC ATC GAT CTT CTA	1133
	Trp Phe Gly Arg Glu Gly Glu Tyr Asn Ala Met Val Ile Asp Leu Leu	
	70 75 80 85	
	GGC CCA TCT TTG GAA GAT TTA TTC AAC TAC TGT CAC AGA AGG TTC TCC	1181
20	Gly Pro Ser Leu Glu Asp Leu Phe Asn Tyr Cys His Arg Arg Phe Ser	
	90 95 100	
	TTT AAG ACG GTT ATC ATG CTG GCT TTG CAA ATG TTT TGC CGT ATT CAG	1229
	Phe Lys Thr Val Ile Met Leu Ala Leu Gln Met Phe Cys Arg Ile Gln	
	105 110 115	

30.

	TAT ATA CAT GGA AGG TCG TTC ATT CAT AGA GAT ATC AAA CCA GAC AAC	1277
	Tyr Ile His Gly Arg Ser Phe Ile His Arg Asp Ile Lys Pro Asp Asn	
	120 125 130	
5	TTT TTA ATG GGG GTA GGA CGC CGT GGT AGC ACC GTT CAT GTT ATT GAT	1325
	Phe Leu Met Gly Val Gly Arg Arg Gly Ser Thr Val His Val Ile Asp	
	135 140 145	
	TTC GGT CTA TCA AAG AAA TAC CGA GAT TTC AAC ACA CAT CGT CAT ATT	1373
	Phe Gly Leu Ser Lys Lys Tyr Arg Asp Phe Asn Thr His Arg His Ile	
	150 155 160 165	
10	CCT TAC AGG GAG AAC AAG TCC TTG ACA GGT ACA GCT CGT TAT GCA AGT	1421
	Pro Tyr Arg Glu Asn Lys Ser Leu Thr Gly Thr Ala Arg Tyr Ala Ser	
	170 175 180	
	GTC AAT ACG CAT CTT GGA ATA GAG CAA AGT AGA AGA GAT GAC TTA GAA	1469
	Val Asn Thr His Leu Gly Ile Glu Gln Ser Arg Arg Asp Asp Leu Glu	
15	185 190 195	
	TCA CTA GGT TAT GTC TTG ATC TAT TTT TGT AAG GGT TCT TTG CCA TGG	1517
	Ser Leu Gly Tyr Val Leu Ile Tyr Phe Cys Lys Gly Ser Leu Pro Trp	
	200 205 210	
	CAG GGT TTG AAA GCA ACC ACC AAG AAA CAA AAG TAT GAT CGT ATC ATG	1565
20	Gln Gly Leu Lys Ala Thr Thr Lys Lys Gln Lys Tyr Asp Arg Ile Met	
	215 220 225	
	GAA AAG AAA TTA AAC GTT AGC GTG GAA ACT CTA TGT TCA GGT TTA CCA	1613
	Glu Lys Lys Leu Asn Val Ser Val Glu Thr Leu Cys Ser Gly Leu Pro	
	230 235 240 245	

31.

	TTA GAG TTT CAA GAA TAT ATG GCT TAC TGT AAG AAT TTG AAA TTC GAT	1661
	Leu Glu Phe Gln Glu Tyr Met Ala Tyr Cys Lys Asn Leu Lys Phe Asp	
	250 255 260	
5	GAG AAG CCA GAT TAT TTG TTC TTG GCA AGG CTG TTT AAA GAT CTG AGT	1709
	Glu Lys Pro Asp Tyr Leu Phe Leu Ala Arg Leu Phe Lys Asp Leu Ser	
	265 270 275	
	ATT AAA CTA GAG TAT CAC AAC GAC CAC TTG TTC GAT TGG ACA ATG TTG	1757
	Ile Lys Leu Glu Tyr His Asn Asp His Leu Phe Asp Trp Thr Met Leu	
	280 285 290	
10	CGT TAC ACA AAG GCG ATG GTG GAG AAG CAA AGG GAC CTC CTC ATC GAA	1805
	Arg Tyr Thr Lys Ala Met Val Glu Lys Gln Arg Asp Leu Leu Ile Glu	
	295 300 305	
	AAA GCT GAT TTG AAC GCA AAT AGC AAT GCA GCA AGT GCA AGT AAC AGC	1853
	Lys Gly Asp Leu Asn Ala Asn Ser Asn Ala Ala Ser Ala Ser Asn Ser	
15	310 315 320 325	
	ACA GAC AAC AAG TCT GAA ACT TTC AAC AAG ATT AAA CTG TTA GCC ATG	1901
	Thr Asp Asn Lys Ser Glu Thr Phe Asn Lys Ile Lys Leu Leu Ala Met	
	330 335 340	
	AAG AAA TTC CCC ACC CAT TTC CAC TAT TAC AAG AAT GAA GAC AAA CAT	1949
20	Lys Lys Phe Pro Thr His Phe His Tyr Tyr Lys Asn Glu Asp Lys His	
	345 350 355	
	AAT CCT TCA CCA GAA GAG ATC AAA CAA CAA ACT ATC TTG AAT AAT AAT	1997
	Asn Pro Ser Pro Glu Glu Ile Lys Gln Gln Thr Ile Leu Asn Asn Asn	
	360 365 370	

32.

	GCA GCC TCT TCT TTA CCA GAG GAA TTA TTG AAC GCA CTA GAT AAA GGT	2045
	Ala Ala Ser Ser Leu Pro Glu Glu Leu Leu Asn Ala Leu Asp Lys Gly	
	375 380 385	
5	ATG GAA AAC TTG AGA CAA CAG CAG CCG CAG CAG CAG GTC CAA AGT TCG	2093
	Met Glu Asn Leu Arg Gln Gln Gln Pro Gln Gln Gln Val Gln Ser Ser	
	390 395 400 405	
	CAG CCA CAA CCA CAG CCC CAA CAG CTA CAG CAG CAA CCA AAT GGC CAA	2141
	Gln Pro Gln Pro Gln Pro Gln Gln Leu Gln Gln Gln Pro Asn Gly Gln	
	410 415 420	
10	AGA CCA AAT TAT TAT CCT GAA CCG TTA CTA CAG CAG CAA CAA AGA GAT	2189
	Arg Pro Asn Tyr Tyr Pro Glu Pro Leu Leu Gln Gln Gln Gln Arg Asp	
	425 430 435	
	TCT CAG GAG CAA CAG CAG CAA GTT CCG ATG GCT ACA ACC AGG GCT ACT	2237
	Ser Gln Glu Gln Gln Gln Gln Val Pro Met Ala Thr Thr Arg Ala Thr	
15	440 445 450	
	CAG TAT CCC CCA CAA ATA AAC AGC AAT AAT TTT AAT ACT AAT CAA GCA	2285
	Gln Tyr Pro Pro Gln Ile Asn Ser Asn Asn Phe Asn Thr Asn Gln Ala	
	455 460 465	
	TCT GTA CCT CCA CAA ATG AGA TCT AAT CCA CAA CAG CCG CCT CAA GAT	2333
	Ser Val Pro Pro Gln Met Arg Ser Asn Pro Gln Gln Pro Pro Gln Asp	
20	470 475 480 485	
	AAA CCA GCT GGC CAG TCA ATT TGG TTG TAA G CAACATATAT TGCTCAAAAC	2384
	Lys Pro Ala Gly Gln Ser Ile Trp Leu *	
	490 495	

33.

	GCACAAAAT AAACATATGT ATATATAGAC ATACACACAC ACATATATAT ATATATATTA	2444
	TTATTATTAT TTACATATAC GTACACACAA TTCCATATCG AGTTAATATA TACAATTCTG	2504
	GCCTTCTTAC CTAAAAAGAT GATAGCTAAA AGAACCACTT TTTTATGCA TTTTTTCTT	2564
	CGGGAAGGAA ATTAAGGGGG AGCGGAGCAC CTCTTGCCA ATTTGTTTTT TTTTATGTA	2624
5	ATAAAGGGCT AAGGATCGAA GATCAATCAC GAATATTGGA CGGTTTAAA GGAGGGCCTC	2684
	TGAGAAGACA GCATCAATTC GTATTTTCGA TAATTAACTT GCCTTATAGT GTCTGATTAG	2744
	GAAACAATCA CGAGACGATA ACGACGGAAT ACCAAGGAAG TTTGTGCAA TATACAGCGG	2804
	GCACAAACAG CAGCTTCACT CAGGTAACT CACATACTGT TGAAAATTGT CGGTATGGAA	2864
	TTCGTTGCAG AAAGGGCTCA GCCAGTTGGT CAAACAATCC AGCAGCAAAA TGTTAATACT	2924
10	TACGGGCAAG GCGTCCTACA ACCGCATCAT GATTIACAGC AGCGACAACA ACAACAACAG	2984
	CAGCGTCAGC ATCAACAACCT GCTGACGTCT CAGTTGCCCC AGAAATCTCT CGTATCCAAA	3044
	GGCAAATATA CACTACATGA CTTCCAGATT ATGAGAACGC TTGGTACTGG ATCC	3098

(2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:

15

(A) LENGTH: 495 amino acids

(B) TYPE: amino acid

(D) TOPOLOGY: linear

34.

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

	Met	Asp	Leu	Arg	Val	Gly	Arg	Lys	Phe	Arg	Ile	Gly	Arg	Lys	Ile	Gly	
	1				5					10					15		
5	Ser	Gly	Ser	Phe	Gly	Asp	Ile	Tyr	His	Gly	Thr	Asn	Leu	Ile	Ser	Gly	
				20					25					30			
	Glu	Glu	Val	Ala	Ile	Lys	Leu	Glu	Ser	Ile	Arg	Ser	Arg	His	Pro	Gln	
				35				40					45				
	Leu	Asp	Tyr	Glu	Ser	Arg	Val	Tyr	Arg	Tyr	Leu	Ser	Gly	Gly	Val	Gly	
10		50					55					60					
	Ile	Pro	Phe	Ile	Arg	Trp	Phe	Gly	Arg	Glu	Gly	Glu	Tyr	Asn	Ala	Met	
	65				70					75					80		
	Val	Ile	Asp	Leu	Leu	Gly	Pro	Ser	Leu	Glu	Asp	Leu	Phe	Asn	Tyr	Cys	
				85					90					95			
15	His	Arg	Arg	Phe	Ser	Phe	Lys	Thr	Val	Ile	Met	Leu	Ala	Leu	Gln	Met	
				100					105					110			
	Phe	Cys	Arg	Ile	Gln	Tyr	Ile	His	Gly	Arg	Ser	Phe	Ile	His	Arg	Asp	
				115				120					125				
	Ile	Lys	Pro	Asp	Asn	Phe	Leu	Met	Gly	Val	Gly	Arg	Arg	Gly	Ser	Thr	
20		130					135					140					

35.

	Val His Val Ile Asp Phe Gly Leu Ser Lys Lys Tyr Arg Asp Phe Asn	
	145	150 155 160
	Thr His Arg His Ile Pro Tyr Arg Glu Asn Lys Ser Leu Thr Gly Thr	
		165 170 175
5	Ala Arg Tyr Ala Ser Val Asn Thr His Leu Gly Ile Glu Gln Ser Arg	
		180 185 190
	Arg Asp Asp Leu Glu Ser Leu Gly Tyr Val Leu Ile Tyr Phe Cys Lys	
		195 200 205
	Gly Ser Leu Pro Trp Gln Gly Leu Lys Ala Thr Thr Lys Lys Gln Lys	
10		210 215 220
	Tyr Asp Arg Ile Met Glu Lys Lys Leu Asn Val Ser Val Glu Thr Leu	
		225 230 235 240
	Cys Ser Gly Leu Pro Leu Glu Phe Gln Glu Tyr Met Ala Tyr Cys Lys	
		245 250 255
15	Asn Leu Lys Phe Asp Glu Lys Pro Asp Tyr Leu Phe Leu Ala Arg Leu	
		260 265 270
	Phe Lys Asp Leu Ser Ile Lys Leu Glu Tyr His Asn Asp His Leu Phe	
		275 280 285
	Asp Trp Thr Met Leu Arg Tyr Thr Lys Ala Met Val Glu Lys Gln Arg	
20		290 295 300

36.

	Asp	Leu	Leu	Ile	Glu	Lys	Gly	Asp	Leu	Asn	Ala	Asn	Ser	Asn	Ala	Ala	
	305					310					315					320	
	Ser	Ala	Ser	Asn	Ser	Thr	Asp	Asn	Lys	Ser	Glu	Thr	Phe	Asn	Lys	Ile	
						325				330					335		
5	Lys	Leu	Leu	Ala	Met	Lys	Lys	Phe	Pro	Thr	His	Phe	His	Tyr	Tyr	Lys	
				340					345					350			
	Asn	Glu	Asp	Lys	His	Asn	Pro	Ser	Pro	Glu	Glu	Ile	Lys	Gln	Gln	Thr	
				355				360					365				
	Ile	Leu	Asn	Asn	Asn	Ala	Ala	Ser	Ser	Leu	Pro	Glu	Glu	Leu	Leu	Asn	
10		370				375					380						
	Ala	Leu	Asp	Lys	Gly	Met	Glu	Asn	Leu	Arg	Gln	Gln	Gln	Pro	Gln	Gln	
	385					390				395				400			
	Gln	Val	Gln	Ser	Ser	Gln	Pro	Gln	Pro	Gln	Pro	Gln	Gln	Leu	Gln	Gln	
				405				410					415				
15	Gln	Pro	Asn	Gly	Gln	Arg	Pro	Asn	Tyr	Tyr	Pro	Glu	Pro	Leu	Leu	Gln	
				420				425					430				
	Gln	Gln	Gln	Arg	Asp	Ser	Gln	Glu	Gln	Gln	Gln	Gln	Val	Pro	Met	Ala	
				435				440					445				
20	Thr	Thr	Arg	Ala	Thr	Gln	Tyr	Pro	Pro	Gln	Ile	Asn	Ser	Asn	Asn	Phe	
		450				455				460							

37.

Asn Thr Asn Gln Ala Ser Val Pro Pro Gln Met Arg Ser Asn Pro Gln
465 470 475 480

Gln Pro Pro Gln Asp Lys Pro Ala Gly Gln Ser Ile Trp Leu *
485 490 495

38.

The invention now being fully described, it will be apparent to one of ordinary skill in the art that various changes and modifications can be made without departing from the spirit or scope of the invention.

39.

CLAIMS

1. A DNA sequence encoding a polypeptide with defective tyrosine kinase activity, wherein the polypeptide is characterized as:

- (a) promoting normal mitotic recombination; and
- (b) being essentially unable to repair a DNA double-strand break which occurs at the cleavage site:

CAACAG
GTTGTC
↑

2. The DNA sequence of claim 1, wherein the break is induced by an endonuclease.
3. The DNA sequence of claim 2, wherein the endonuclease is *HO*.
4. The DNA sequence of claim 1, selected from the group consisting of:
- (a) cDNA having a nucleotide sequence derived from the genomic coding region of the polypeptide;
- (b) DNA sequences encoding an amino acid sequence having at least about 35% homology in the protein kinase domain with the amino acid sequence encoded by the cDNA of (a); and
- (c) DNA sequences which are degenerate as a result of the genetic code with respect to the DNA sequences of (a) and (b).

40.

5. The DNA sequence of claim 1 which is *hrr25* gene.
6. The DNA sequence of claim 1, wherein the DNA sequence is derived from a yeast.
7. A host cell containing the DNA sequence of claim 1.
8. The host cell of claim 7 wherein the DNA sequence is introduced by transformation or transfection.
9. A biologically functional plasmid or viral DNA vector comprising the DNA sequence of claim 1.
10. A functional polypeptide encoded by all or a portion of the DNA sequence of claim 1.
11. A polypeptide with defective tyrosine kinase activity, wherein the polypeptide is characterized as:
 - (a) promoting normal mitotic recombination, and
 - (b) being essentially unable to repair a DNA double-strand break including those which occur at the cleavage site:

CAACAG
GTTGTC
↑

12. The polypeptide of claim 11, wherein the break is induced by an endonuclease.

41.

13. The polypeptide of claim 12, wherein the endonuclease is *HO*.
14. An antibody to the polypeptide of claim 11.
15. The antibody of claim 14, which is a monoclonal antibody.
16. An antibody to the polypeptide of claim 10.
17. The antibody of claim 16, which is a monoclonal antibody.
18. A method of identifying DNA encoding functional polypeptide with tyrosine kinase activity capable of restoring DNA double-strand break repair activity in the host of claim 6, which comprises:
 - (a) screening a library of DNA for sequences capable of producing the polypeptide; and
 - (b) identifying DNA encoding polypeptide capable of restoring double-strand break activity.
19. The method of claim 18, wherein the DNA is mammalian DNA.
20. The method of claim 19, wherein the mammalian DNA is human DNA.
21. The method of claim 18, wherein the screening detects structural similarities between members of the DNA library or expression products thereof and the screening means.
22. The method of claim 21, wherein the screening means are based on nucleic acid structure or antigenic structure.

42.

23. The method of claim 18, wherein the screening detects functional similarities between the expression products of the DNA library and the tyrosine kinase activity of the host.
24. The method of claim 23, wherein the functional similarities are detected by complementation.
25. The method of claim 24, wherein the complementation measures restoration of resistance to a DNA double-strand break.
26. The method of claim 25, wherein the DNA double-strand break is induced by a radiomimetic alkylating agent.
27. The method of claim 26, wherein the radiomimetic alkylating agent has methylmethane sulfonate activity.
28. The method of claim 27, wherein the agent is methylmethane sulfonate.
29. The method of claim 25, wherein the DNA double-strand break is induced by an endonuclease.
30. The method of claim 29, wherein the endonuclease is *HO*.
31. The method of claim 25, wherein the DNA double-strand break is X-ray induced.
32. The method of claim 18, wherein the host is a yeast.
33. The method of claim 32, wherein the yeast is a member of the genus *Saccharomyces*.

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34. The method of claim 33, wherein the yeast is *Saccharomyces cerevisiae*.
35. An isolated DNA sequence encoding a polypeptide with tyrosine kinase activity, wherein the polypeptide is capable of restoring DNA double-strand break repair activity in the host of claim 6.
36. The DNA sequence of claim 35, selected from the group consisting of:
- (a) cDNA having a nucleotide sequence derived from the genomic coding region of the polypeptide;
 - (b) DNA sequences encoding an amino acid sequence having at least about 35% homology in the protein kinase domain with the amino acid sequence encoded by the cDNA of (a); and
 - (c) DNA sequences which are degenerate as a result of the genetic code with respect to the DNA sequences of (a) and (b).
37. The DNA sequence of claim 35, which is a mammalian DNA.
38. The mammalian DNA sequence of claim 37, which is a human DNA.
39. An isolated DNA sequence identified by the method of claim 18.
40. An isolated polypeptide capable of restoring DNA double-strand break repair activity in the host of claim 6 or functional fragments thereof, wherein the polypeptide is free from other polypeptides with which it is associated in nature.

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41. An isolated polypeptide encoded by all or a functional portion of the DNA sequence of claim 35.

42. The polypeptide of claim 40, which is a mammalian polypeptide.

43. The mammalian polypeptide of claim 42, which is a human polypeptide.

44. An antibody to the polypeptide of claim 40.

45. The antibody of claim 44, which is a monoclonal antibody.

46. An antibody to the polypeptide of claim 41.

47. The antibody of claim 46, which is a monoclonal antibody.

48. A method for identifying a composition which affects the activity of a mammalian polypeptide having tyrosine kinase activity, wherein the polypeptide is capable of restoring DNA double-strand break repair activity in the host of claim 6, the method comprising:

5 (a) incubating components comprising the composition and the mammalian polypeptide in the presence of the host, wherein the incubating is carried out for a period of time and under conditions sufficient to allow the components to interact; and

10 (b) measuring the change in tyrosine kinase activity caused by the system.

49. The method of claim 48, wherein the change in step (b) correlates with decreased repair of DNA double-strand breaks.

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50. The method of claim 49, wherein the DNA double-strand break is induced by a radiomimetic alkylating agent.
51. The method of claim 50, wherein the radiomimetic alkylating agent has methylmethane sulfonate activity.
52. The method of claim 51, wherein the agent is methylmethane sulfonate.
53. The method of claim 49, wherein the DNA double-strand break is induced by an endonuclease.
54. The method of claim 53, wherein the endonuclease is *HO*.
55. The method of claim 49, wherein the DNA double-strand break is X-ray induced.
56. The method of claim 48, wherein the affect of the molecule is to inhibit the polypeptide.
57. The method of claim 48, wherein the mammalian polypeptide is a human polypeptide.

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HRR25	1/	MDLRVGRKFRIGRIGSGSFGD	IYHGTN	I	---	SGEEVAIK	ESIRS	---	RHPQLDYESRMYRYL	SG
CDC28	1/	MSGELANYKRLEKVGE	GTYGVMVKAL	D	---	PGGQRVWAK	KIRLESEDEGPSTAIREISL	KE	L	K
K991	1/	MARTITFDIPSQYKLVDL	IGEGAYGTVC	SAIHKP	---	SGIKVAIK	KIQPF	SKKL	-FVTRTIREIK	IRYFHE
RAF1	346/	SEVMLSTRIGEGSFG	GTVMKGVHG	---	---	DVAMKIL	KVVDPTPEQ	QAFRNEVA	IRKT	-R
HRR25	62/	GVGTPFIRWFGREG	---	EYNAMVI	D	LGPS	LED	FN	MYCHRR	---
CDC28	66/	DDNIVRLYDIVHSDA	---	HKLYL	VF	EF	LDL	---	DLKRYMEGIPK	DQP-LGADIVKFKMMQLCKGIAMCHSH
K991	68/	HENIISILDKVRPVS	IDKLNAYL	VEEL	MET	---	DLQKVINNQNSG	STLS	DDHVQYFTYQILRALKSIHSA	
RAF1	401/	HVNILLFMGYMTK	---	DNLA	IMTQWCEGS	---	SLYKHL	HVQETK	---	EQMFQLIDIA
HRR25	123/	SFIHRDIKPNF	MGVGRRGSTV	HVIDFGL	SKKYRDFN	THRHIP	-YRENKSL	TGTARYASV	NTH	---
CDC28	116/	RILHRDLKPN	LNLLINKDG	---	NLKL	GDFGLARAF	GVPLRAY	---	THEIVTLWYRAPELL	---
K991	122/	QVIHRDIKPS	NLLNSNC	---	DLKVCD	DFGLARCL	ASSDSRETL	VGFMETEYVATR	WYRAPEIML	---
RAF1	461/	NIHRDMKSN	NIIFLHEGL	---	TVKIGD	EGLATVKSRWSGSQV	---	EQPTGSVL	MAPEVIRMQDNNPF	
HRR25	190/	SRRDLES	SLGYMLIYFCK	GLSPVQQL	KATTKKQKY	DRIMEK	KLNV	---	SVET	QSG
CDC28	190/	STGVD	TVSI	GCIF	AEMQNRKP	IF	SEDSEI	---	DQIFKIFRVL	GTP-NEAIWPDIVYLPDFKPSFPQWRRKD
K991	203/	ITAMD	WSCGC	ILAE	MVSGKPL	FPGRDYH	---	HQLW	IL	EVLGTPSFEDFNQIKSKRAKEYIANLPMPRPPLP
RAF1	524/	SFQSD	VYSYGIV	LYELMT	GELPYSHI	---	---	NNRQ	QI	IFMVGRG--YASPD

FIG.1A

HRR25	243/	-----LPLEFQEQYMAVQK Q NLKF Q E K Q PDYLF Q ARLFK Q S IK Q EYHNDHLFDWTMLRYTKAMVEKQ Q RDL
CDC28	257/	-----LSQVVPS-----LDPRGIDL Q DKLLAYDPINRISARRAAI--HPYFQES
K991	276/	-----WETVWSKT Q LNPD Q MI Q DL Q DKMLQFN Q PKRISAAEA
RAF1	574/	-----QPKAMKRLVAD Q VKKVKE Q E R PLFPQILSSIEL Q QHS Q
HRR25	288/	LIEKGDNLANSNAASNSTDNKSETFNKIKILLAMKKFPTHFYKNE Q DKHNPSPEEIKQQTILNNNAASSL
HRR25	361/	PEELLNALKGMENLRQQPQQQVQSSQPPQPPQQLQQQPNQGQRPNYYPEPLLQQQQRDSQEQQQVPMATT
HRR25	451	RATQYPPQINSN Q NFN Q TN Q ASVPPQMRSNPQQPPQDKPAGQSIWL

FIG.1A(CONT.)



FIG.1B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/05565

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : Please See Extra Sheet.

US CL : 435/6, 17, 194, 240.1, 252.3, 320.1; 530/387.1, 388.26; 536/27

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 435/6, 7.4, 15, 194, 240.1, 252.3, 320.1; 530/300, 350, 387.1, 388.26; 536/27

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	Journal of Cellular Biochemistry, Supplement 15A, issued 1991, M.F. Hoekstra et al, "A gene product from yeast associated with the repair of damaged DNA encodes a protein kinase", page 156, entire document.	1-13, 35-41 14-34, 42-57
Y	S.L. Berger et al., "Methods in Enzymology", Volume 152, published 1987 by Academic Press (N.Y.), pages vi-x, entire document.	18-34, 42-43
Y	"Methods in Enzymology", Volume 70, published 1980 by Academic Press (N.Y.), pages 49-70, entire document.	14-17, 44-47
Y	Biochemical and Biophysical Research Communications, Volume 170, No. 1, issued 16 July 1990, D.C. Gaudette et al, "Effect of genistein, a tyrosine kinase inhibitor, on U46619-induced phosphoinositide phosphorylation in human platelets", pages 238-242, especially pages 239-240.	48-57

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* "A"	document defining the general state of the art which is not considered to be part of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 31 July 1992	Date of mailing of the international search report 10 AUG 1992
Name and mailing address of the ISA/ Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. NOT APPLICABLE	Authorized officer GABRIELE E. BUGAISKY Telephone No. (703) 308-4201

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/05565

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Science, Volume 241, issued 01 July 1988, S.K. Hanks et al, "The protein kinase family: Conserved features and deduced Phylogeny of the catalytic domains", pages 42-52, entire document.	1-57

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US92/05565

A. CLASSIFICATION OF SUBJECT MATTER:

IPC (5):

C07H 21/04; C07K 15/00, 15/28; C12N 1/00, 5/10, 9/12, 15/00; C12Q 1/48, 1/68

B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

Sequence Databases: Geneseq, Genbank/EMBL, PIR, SwissProt; APS; Dialog: Medline, Biosis, Embase, Biotech. Abs.

search terms: tyrosine kinase, ligase, ligation, recombination, repair, HO, endonuclease, nuclease, AU=Hoesktra, complement?, screen?, library, complementation, HHR, yeast, saccharomyces, enzyme, antibod?, monoclonal, DT=review, agonist, antagonist, inhibit?, activity